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PB80-102734

Assessment of Macroinvertebrate Monitoring Techniques in an Energy Development Area: A Test of the Efficiency of Three Macrobenthic Sampling Methods in the White River

Environmental Monitoring and Support Lab, Las Vegas, NV

Jul 79

United States
Environmental Protection
Agency

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and Support Laboratory
P. O. Box 15027
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EPA-600/7-79-163
July 1979

PB80-102734

Research and Development

EPA

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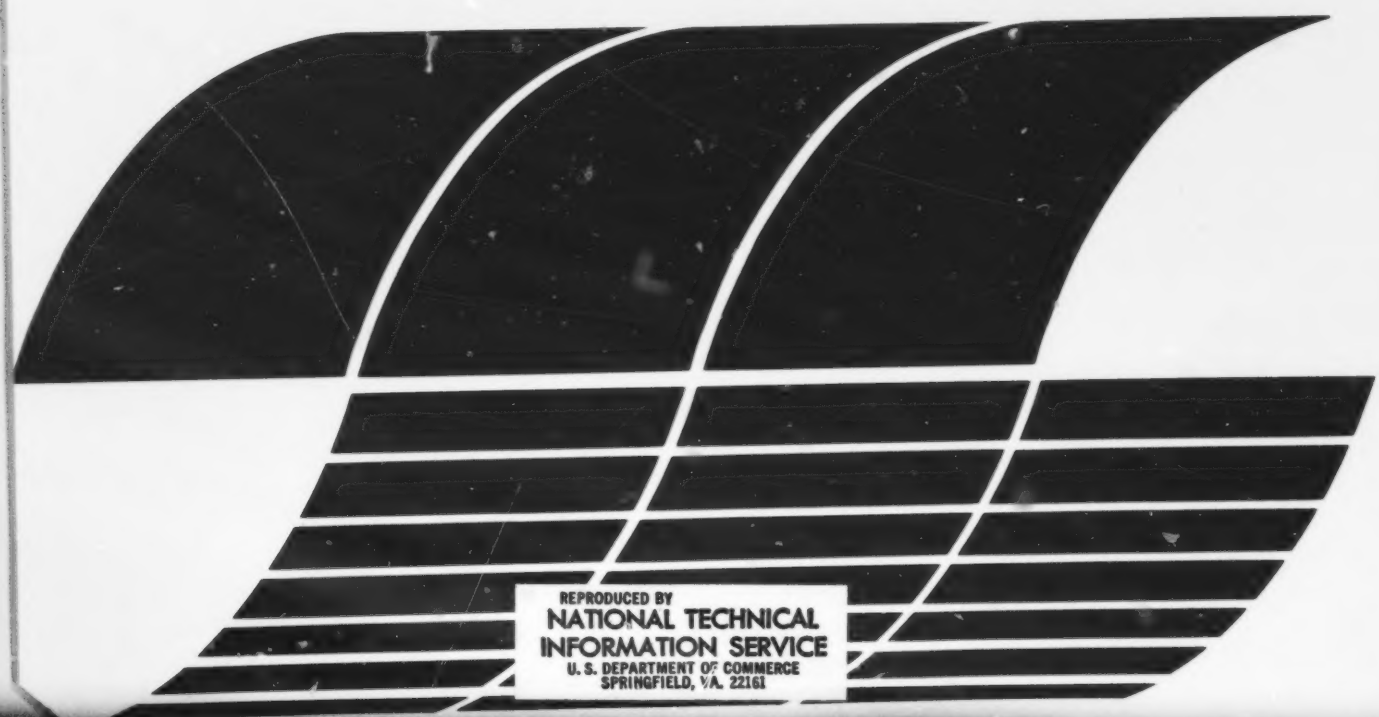
A Test of the Efficiency of Three Macrobenthic Sampling Methods in the White River

Interagency Energy-Environment Research and Development Program Report



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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-163	2.
3. RECIPIENT'S ACCESSION NO. PB 80-102734	
4. TITLE AND SUBTITLE ASSESSMENT OF MACROINVERTEBRATE MONITORING TECHNIQUES IN AN ENERGY DEVELOPMENT AREA: A test of the efficiency of three macrobenthic sampling methods in the White River.	5. REPORT DATE July 1979
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J.E. Pollard* and W.L. Kinney	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Monitoring and Support Laboratory U.S. Environmental Protection Agency, and Biology Department, University of Nevada, Las Vegas	10. PROGRAM ELEMENT NO. 1NE625ABZ
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency-Las Vegas, NV Office of Research and Development Environmental Monitoring and Support Laboratory Las Vegas, Nevada 89114	13. TYPE OF REPORT AND PERIOD COVERED Final 1977-1978
	14. SPONSORING AGENCY CODE EPA/600/07

15. SUPPLEMENTARY NOTES
*Biology Department, University of Nevada, Las Vegas, Las Vegas, Nevada 89154

16. ABSTRACT Three methods of macroinvertebrate collection were evaluated for selectivity, reproducibility, capture-effectiveness, and cost efficiency in the White River near Meeker, Colorado. Samples were collected with a standard Surber sampler, with a portable invertebrate box sampler (PIBS), and using the standardized traveling kick method (STKM). Methods were evaluated in riffles of the White River directly upstream and downstream from the confluence of Piceance Creek, as well as at a comparable riffle at an upstream control station. The traveling kick method collected the largest number of animals and taxa per sample with equivalent or lower variability than the other two methods tested. While Surber samplers and the PIBS performed similarly in the vicinity of Piceance Creek, their performance differed at the upstream control station where the PIBS collected more animals and taxa per sample than the Surber sampler. Similarly, while sample processing time did not significantly differ for the various methods of collection used at any station in the vicinity of Piceance Creek, differences did exist at the upstream control station with kick samples requiring the greatest amount of processing time and Surbers requiring the least. The cost efficiency of various methods was estimated by calculating the number of animals processed per unit time and the number of hours required to provide standing crop estimates for each sample within a given precision level. Cost-efficiency estimates indicated that the STKM was superior to the Surber or PIBS methods, particularly at the station near Piceance Creek.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Benthos Limnology Sampling Water Pollution Environmental Monitoring Aquatic Biology Oil Shale Industry	Semiarid regions Macroinvertebrates Standardized traveling-kick method Portable invertebrate-box sampler Surber Sampler White River, Colorado	08H 14A,D

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 36
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE A03 – A01

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

☆U.S. GOVERNMENT PRINTING OFFICE: 1979-683 091

EPA-600/7-79-163
July 1979

ASSESSMENT OF MACROINVERTEBRATE MONITORING TECHNIQUES IN AN ENERGY DEVELOPMENT AREA

A Test of the Efficiency of Three Macrobenthic Sampling Methods in the White River

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FOREWORD

Protection of the environment requires effective regulatory actions that are based on sound technical and scientific data. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach that transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- development and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs.

The relative efficiencies of three macroinvertebrate collection methods are assessed in this report with reference to their use in areas of oil shale development. Results presented herein can be used as a basis for developing water quality monitoring programs for streams of the semiarid western regions. Potential users of the information presented include federal, state, and local environmental and health agencies, as well as private organizations engaged in water quality monitoring and assessment. Further information is available from the Water and Land Quality Branch, Monitoring Operations Division.

George B. Morgan
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SUMMARY

The use of benthic macroinvertebrates as indicators of water quality has become standard practice for many water quality monitoring programs. It has been demonstated that the conventional macroinvertebrate sampling methods used in the eastern and subhumid regions of the United States do not provide useful data in many instances in the semiarid western United States. Since the West holds much of the country's coal and oil shale reserves, it is imperative that reliable methods for biomonitoring be available before massive energy development occurs. The purpose of the present study was to evaluate the efficiencies of three methods of macroinvertebrate sampling in a prototype river of the semiarid west.

Three methods of macroinvertebrate collection were evaluated for selectivity, reproducibility, capture-effectiveness, and cost efficiency in the White River near Meeker, Colorado. Samples were collected with a standard Surber sampler, with a portable invertebrate box sampler (PIBS), and using the standardized traveling kick method (STKM). The methods were evaluated in riffles of the White River directly upstream and downstream from its confluence with Piceance Creek as well as at a comparable riffle at an upstream control station.

The STKM collected more animals and taxa per sample with equivalent or lower variability than the other two methods tested. While the Surber sampler and the PIBS performed similarly in the vicinity of Piceance Creek, their performance differed at the upstream control station where the PIBS collected more animals and taxa per sample than the Surber sampler. Similarly, while sample processing time did not significiantly differ from the various methods of collection used at any station in the vicinity of Piceance Creek, differences did exist at the upstream control station with kick samples requiring the greatest amount of processing time and Surber samples requiring the least.

The cost efficiency of various methods was estimated by calculating the number of animals processed per unit time and the number of hours required to provide standing crop estimates for each sample within a given level of precision. Cost-efficiency estimates indicated that the STKM was superior to the Surber or PIBS methods, particularly at the stations in the vicinity of Piceance Creek.

Selectivity of sampling methodologies was evident at all stations during all seasons. In general, the small-area Surber sampler and PIBS collected the more tightly adherent forms such as Hydroptila sp. most efficiently

while the STKM was more efficient at collecting the more loosely attached forms such as the swimming mayfly Baetis sp.

It is one of the missions of the U.S. Environmental Protection Agency to provide guidance in terms of biological monitoring methodology. Results of this study will serve to improve the efficiency of biological monitoring programs by identification of appropriate techniques for application in semiarid regions including energy development areas.

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INTRODUCTION

This report evaluates biological monitoring approaches and techniques tested in a short segment of the White River that may be impacted by oil shale development activities. The evaluation is based on testing conducted in a stream reach that is subject to impact by activities associated with construction and operation of commercial-scale oil shale industries on two federally leased oil shale tracts in Colorado's Piceance Basin. Specifically, the report examines stream sampling methodologies and procedures for purposes of characterizing macroinvertebrate communities, detecting and quantifying changes in community composition and structure, and associating such changes with causative factors to the extent possible. Aspects of macroinvertebrate sampling evaluated include: sampling techniques and devices; parameter selection (e.g., standing crop, number of taxa, etc.); sampling schedules and intensity; and individual sample site selection and station distribution.

As the focus in this country turns to energy development, efficient methods for evaluating the environmental consequences of large-scale energy production become of paramount interest. In the near future, streams of the semiarid western United States will be impacted by intensive energy development in the form of oil shale and coal mining and processing activities. These activities may result in the release of a variety of pollutants into our waterways including a vast array of potentially toxic substances. It is extremely critical, therefore, that efficient methods for monitoring the ecological effects of massive energy development on our western waterways be available for use by regulatory agencies and industry as these activities increase in intensity.

Currently, biological monitoring procedures appropriate for application to waterways of the western energy resource areas are not well developed. The U.S. Environmental Protection Agency (USEPA) has been strongly criticized for failing to provide biological monitoring guidelines for the assessment of water quality and receiving waters as required by the Federal Pollution Control Act Amendments of 1972 [PL 92-500 (Westman 1977)]. While guidelines are urgently needed nationwide, it must be recognized that biological monitoring requirements vary widely from one area to another. The methods which are to be used for biological monitoring of receiving waters must be tailored to meet the specific regional monitoring requirements which vary from one geographical region to another as well as within geographical regions.

It has become increasingly obvious that biological monitoring strategies and techniques traditionally utilized in subhumid and humid regions of the country are not necessarily well suited for application in semiarid regions of the western United States where much of the energy resource development is occurring. This is particularly relevant with respect to utilization of stream bottom-dwelling macroinvertebrates as environmental indicators in water quality assessment programs for streams which may be affected by oil shale developmental activities. Conventional sampling techniques and devices are of limited utility for aquatic macroinvertebrate investigations in streams that receive most of their flow from snowpack runoff, resulting in high discharge levels from April through July and low base flow during much of the remainder of the year. Periodic intense thundershowers, although typically localized and of short duration, result in episodic high flows which further complicate conventional biomonitoring approaches. During high water stages, use of conventional unit-area samplers is impossible. For example, utilization of the Surber sampler is restricted to water of less than 18 inches in depth. The inherent patchy distribution of macroinvertebrates in these streams further restricts the utility of small area samplers because large numbers of samples are required to provide adequate representation of communities in a given habitat. The suspended sediments and bed load carried in these streams, in combination with highly variable flow patterns, frequently create unstable substrates for maintenance of macroinvertebrate populations.

Stream-dwelling macroinvertebrates have long been used by aquatic ecologists for purposes of evaluating water quality and ecological stability. Macroinvertebrates are ideally suited for this purpose since they are easy to sample, relatively immobile and consequently unable to avoid unfavorable conditions, and are sensitive in varying degrees to most types of pollution. Since most aquatic insects have life cycles of a year or more, any alteration in community structure caused by pollution will remain in evidence for a fairly long period (Hilsenoff 1977). For the above reasons, information regarding the structure of macroinvertebrate communities can provide a vivid portrait of the recent water quality history of a stream. For example, perturbations in the macroinvertebrate community structure can reflect the impacts of single, short-duration pollution events that would be easily missed by periodic physical/chemical monitoring alone.

Many methods have been developed for collecting macroinvertebrates in riffle substrates, ranging from the well-known Surber sampler to the qualitative window screen method. Surber samplers have long been considered the quantitative standard for the collection of benthic invertebrates (Hynes 1970). It has been pointed out by Kroeger (1972), however, that the Surber sampler provides, at best, a biased estimate of benthic standing crop and is selective for various species of the benthic community. Chutter (1972) also pointed out the ineffectiveness of the Surber sampler in depths over 30 cm.

Use of enclosed box-type samplers eliminates some of the problems associated with Surber samplers (Hynes 1971), but the early designs, such as the Hess sampler, were somewhat cumbersome. Recently, Ellis-Rutter Associates developed a portable invertebrate box sampler (PIBS) which is

relatively easy to use in flowing waters and reportedly performs better than the Surber sampler for estimating standing crop of riffle organisms (Ellis-Rutter Associates 1973). Both Surber and box samplers, however, are difficult to use in rapidly flowing waters and are restricted to use in shallow riffle areas (Frost, Huni, and Kershaw 1971).

In addition to being restricted to shallow water use, small-area samplers such as the PIBS and Surber sampler collect samples with high replicate variability. Average coefficients of variation for Surber samples range from 50 percent (USEPA 1973) to over 80 percent for samples taken from fauna-poor uniform riffle areas (Hornig and Pollard 1978). It is inevitable that samples collected using small-area methods will have relatively high variability due to the inherent patchiness of the macrobenthic fauna.

Methodologies that have the lowest possible sample variability associated with them and yet still collect a relatively large number of organisms and taxa per sample are optimal for biological monitoring programs. Kick samples, collected by kicking up riffle substrates with subsequent entrapment of debris and organisms in a net held downstream from the investigator, have been used to: 1) facilitate the sampling process (Frost, Huni, and Kershaw 1971; Hynes 1970), and 2) to increase precision of the samples and expedite the sampling process (Kinney, Pollard, and Horning 1978; Horning and Pollard 1978). For example, approximately three 30-second traveling kick samples can be collected and field-processed in the time required to collect and process a single Surber sample (Kinney, Pollard, and Horning 1978).

CONCLUSIONS

1. In the present study, the STKM was the most efficient method of macroinvertebrate collection in terms of capture-effectiveness, cost efficiency, and reproducibility of replicate samples collected from rocky bottom substrates.

2. The methods tested for macroinvertebrate collection efficiency varied in performance according to season. The seasonality of macroinvertebrate communities is therefore a significant factor in biological monitoring design considerations for rivers of the semiarid west including the White River adjacent to the Piceance Basin oil shale developments.

3. Processing time for all samples collected downstream from Piceance Creek was significantly higher than for those samples collected upstream from Piceance Creek. This held true for all sampling methods because of the high content of filamentous algae in downstream samples. The STKM, on the other hand, provided better cost-efficiency estimates than either the Surber sampler or the PIBS for collections in this area.

4. All methods of collection were selective to some degree with the Surber sampler and the PIBS collecting tightly adherent forms more efficiently and the standardized traveling kick method more effectively collecting the loosely attached forms.

RECOMMENDATIONS

The recommendations contained herein apply to the Colorado portion of the White River that is potentially subject to impact by oil shale developments. In addition, these recommendations are designed to aid in the implementation of biological designs for streams and rivers of the western United States.

1. It is recommended that riffle habitats similar to those in the vicinity of Piceance Creek (which contain high amounts of filamentous algae) be sampled by the standardized traveling kick method. This is recommended because this method provided the largest number of organisms per sample with the lowest replicate variability, and no increase in time required for sample processing relative to other methodologies tested.

2. Since the standardized traveling kick method was decidedly superior or at least as effective as the Surber sampler and PIBS in terms of collection efficiency, cost efficiency, and ease of sampling, this method is recommended for use in streams with characteristics similar to those of the study reach. This method is particularly applicable in fauna-poor stream reaches with patchy macroinvertebrate distributions.

3. It is recommended that comparisons of stations or sites within a river system be restricted to stream habitats with similar substrate composition. Only in this way can valid comparisons between locations be made since different benthic substrates support different benthic communities.

4. Because single-season sampling did not provide adequate representation of the major taxa inhabiting the White River, it is recommended that sampling be conducted at least during the spring and fall. Until further investigations are conducted, it is not known whether sampling in two seasons is sufficient to generally characterize the benthic macrofauna of western streams, including the White River.

5. The utility of small-area samplers should not be disregarded for use in relatively productive stream reaches where estimates of standing crop may be a major concern. Under these circumstances, an enclosed design sampler such as the PIBS is recommended over the open-frame Surber sampler because of the higher efficiency of the box-type sampler.

STUDY AREA

The White River drainage area may contain the most significant undeveloped, energy mineral resource in the Colorado River Basin in the form of oil shale deposits in the sedimentary rock of the Green River Formation. The richest and thickest known oil shale deposits occur in Colorado's Piceance Basin, and the largest shale-bearing area of the Green River Formation lies in the Uinta Basin of Utah (USDI 1973). Large portions of both these areas drain to the White River.

The White River originates in the dissected lava plateaus of the western slope of Colorado's Rocky Mountains and terminates in the semiarid plains of Utah's Uinta Basin where it joins the Green River within the bounds of Uintah-Ouray Indian Reservation. Annual precipitation ranges from more than 60 centimeters in the high headwater plateaus to less than 18 centimeters at lower elevations (USDI 1973). Most of the precipitation falls as snow at high elevations, and runoff from the snowpack is fairly gradual. Conversely, summer and fall thundershowers, which account for much of the precipitation at lower elevations, result in rapid overland runoff of suspended sediment- and mineral-laden waters.

The headwaters of the White River are in a relatively primitive forested area that is impacted little by man's activities. Although iron and zinc concentrations have been reported in excess of criteria standards (Fox 1977), water quality in the upper reaches is generally good. The river in the upstream reaches supports good trout populations and a diversified invertebrate fauna. The river rapidly deteriorates in quality, partially as a result of nonpoint-source-pollution loading, both natural and man-induced. The river becomes increasingly turbid downstream, and chemical water quality similarly undergoes a pronounced change characterized by a great increase in dissolved solids. The downstream reaches are subject to rapid fluctuations in flow and sediment transport, both suspended and bedload, resulting in a rather meager warm-water fishery and a relatively unstable macroinvertebrate fauna.

The study area of the White River addressed in this report is limited to the stream reach in the immediate vicinity of the Piceance Creek confluence and a control area upstream from Meeker, Colorado (Figure 1). Three sampling stations were selected. One station was designated as the "upstream control" station (WR 230, Figure 1) and was located in an area southeast of Meeker, Colorado, near Rio Blanco County Road RB4, upstream from any significant pollution inputs. The other two stations were located on the White River directly upstream (WR 140) and downstream (WR 130) from its confluence with Piceance Creek (Figure 1). These stations were designated as "upstream" and "downstream" from Piceance Creek. The river in the vicinity of Piceance Creek receives moderate levels of nonpoint source pollutants in the form of

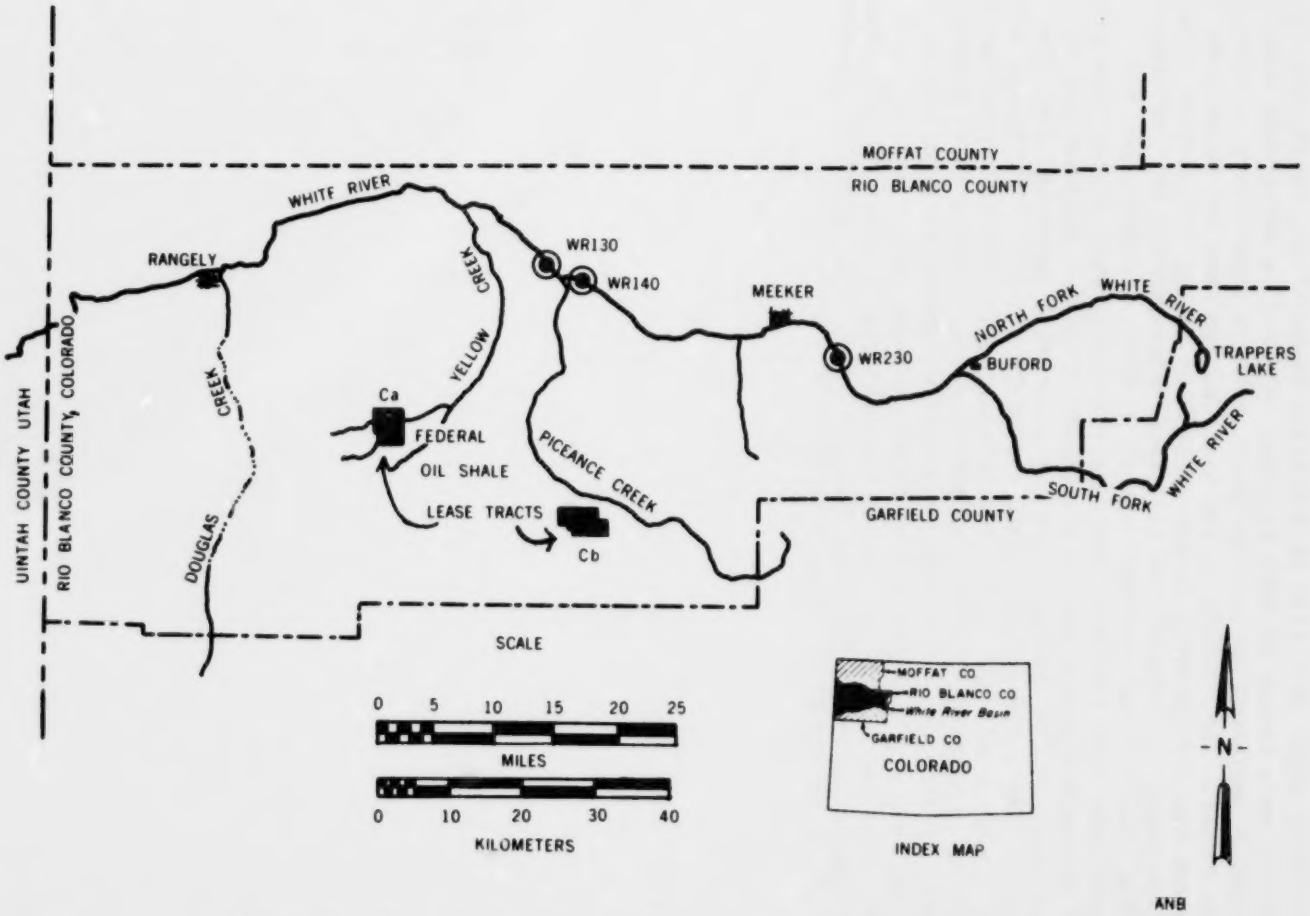

Figure 1. Map of the Study Area and Locations of Sampling Stations on the White River, Colorado.

dissolved solids and suspended sediments. Piceance Creek is a potential source of increased pollution to the river as a result of the ongoing oil shale development in the Piceance Basin.

Uniform riffle areas with similar substrate composition, depth, and flow characteristics were chosen at each station. All riffle substrates sampled were composed of medium-sized (10- to 20-cm) cobbles underlain by a mixture of sand and gravel. The riffles at the stations upstream and downstream from Piceance Creek had considerably larger amounts of patchy filamentous algal growths (Cladophora sp.) during the fall and larger amounts of algal debris in the spring than did the upstream control station. In addition, the station downstream from Piceance Creek was noticeably more silted than either of the two upstream stations during the spring of 1978. Observations of riffle substrates at the stations near Piceance Creek suggested that the Creek might influence the silting characteristics of riffle substrates within the sphere of its direct influence. No substantiation for this hypothesis could be found in historical suspended sediment data (Pennak 1974; Everhart and May 1973) or from determinations of suspended sediments from samples collected upstream and downstream from Piceance Creek during spring, 1978 [461 mg per liter and 453 mg per liter, respectively (Pollard, unpublished data)]. It has also been shown that Piceance Creek is a major contributor of dissolved solids to the White River (Pennak 1974).

MATERIALS AND METHODS

SAMPLING METHODS

Three methods of macroinvertebrate collection were used in this study (Figure 2). Samples were collected using: 1) a standard 0.093-m^2 (1 square foot) Surber sampler with a 90-cm-long, conical-shaped net; 2) a Rutter-Ellis portable invertebrate box sampler (PIBS) with a 76-cm-long, conical-shaped net; and 3) a standardized traveling kick method (STKM) using a triangular dip net with a mouth opening of 28 cm by 28 cm by 24 cm, and a 76-cm-long conical-shaped net held downstream from the investigator to collect organisms dislodged by kicking the substrate. All nets were constructed of Nitex® #571 netting ($\simeq$30 mesh).

Surber and PIBS samples were collected by the methods outlined in Needham and Needham (1962) for the collection of Surber samples. Individual sampling sites for collecting Surber and PIBS samples were chosen where rocks were visibly piled [selection of rich sites as described by Horning and Pollard (1978)]. All riffle areas were chosen for uniformity of substrate, depth, and current velocity.

Standardized traveling kick samples were collected using the triangular dip net described in the following manner: the collector slowly moved downstream, vigorously kicking the substrate and holding the net in his forward path. All kick samples were standardized by holding the net in the water for 30 seconds and traveling approximately 4 meters downstream. Markers were placed beside the stream for orientation. An area approximately 3/4 by 4 meters (3 m^2) was disturbed during the collection of each standardized traveling kick sample. All samples were collected from uniform riffle areas with comparable substrates by the same investigator. Uniform riffles are those determined by the field investigator to have the least variability of available sampling sites in terms of substrate composition, water depth, and stream flow.

SAMPLING DESIGN

Fall, 1977

Surber and traveling kick samples were collected at the stations upstream and downstream from Piceance Creek during fall 1977 to evaluate the effectiveness of the two sampling methods. Five replicate samples each were collected with a Surber sampler and by the STKM from the riffles at these stations on October 4 and 5, 1977. Each set of five replicate samples constitued a discrete sample set.

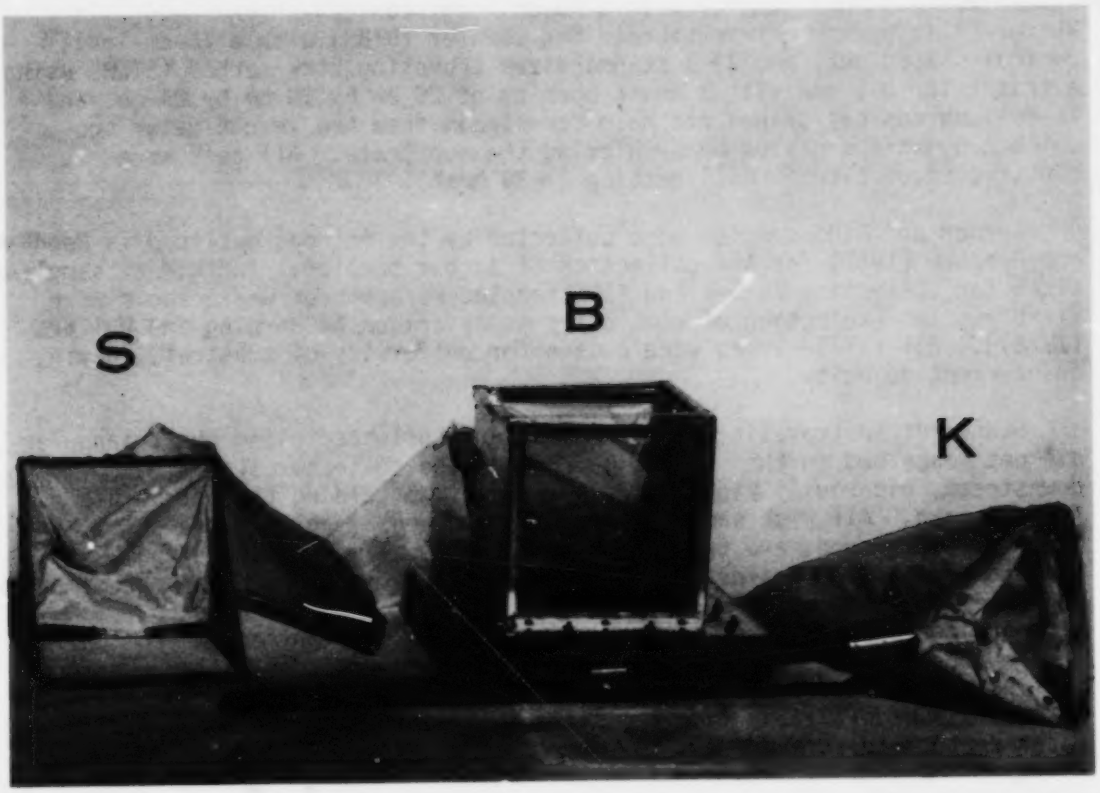

Figure 2. The Surber sampler (S) PIBS (B) and traveling kick net (K).

Spring, 1978

Portable invertebrate box and standardized traveling kick samples were collected at the stations upstream and downstream from Piceance Creek during spring 1978 using the previously stated design. Surber, PIBS, and traveling kick samples were collected at the upstream control station during the same time period. Five replicate samples were collected for each method used at this station. A restricted portion (about 5 by 10 meters in area) of an extremely uniform riffle was used for the collection of all samples. Surber and PIBS sampling sites were selected and then sampled, working in an upstream direction, before traveling kick samples were collected.

SAMPLE PROCESSING

Samples were initially transferred from the Surber sampler, PIBS, and traveling kick nets to a bucket with a 12-strand-per-cm (30 mesh) screen on the bottom to avoid an accidental loss of organisms. Samples were placed in mason jars and preserved with 100 percent Formalin solution in volumes approximately equivalent to the amount of organic debris in the sample, resulting in at least a 5 percent Formalin solution.

In the laboratory, samples were washed clean of Formalin by placing them in a jar covered with a screen of Nitex® 571 netting, pouring off the Formalin, and then rinsing the samples thoroughly with water.

Macroinvertebrates and debris were sorted from gravel and sand by placing the sample in a round-bottom container with water, agitating the sample, and pouring off the debris and organisms. This process was repeated until no organisms could be found in the gravel and sand remaining in the container. Macroinvertebrates were then hand sorted from the debris in a shallow white pan. All macroinvertebrates in the samples were identified to the species level, when possible, and enumerated. Dr. Richard Baumann of Brigham Young University, Provo, Utah, has confirmed the majority of the identifications. Chironomids and simuliids have been identified only to family; generic determinations of chironomids will be addressed in a separate report.

RESULTS

TOTAL COUNT AND NUMBER OF TAXA PER SAMPLE

The standardized traveling kick method collected the largest and the Surber sampler collected the smallest number of animals and taxa per sample at the upstream control station (Table 1). The reproducibility of replicate samples differed distinctly between sampling methods as evidenced by the coefficients of variation associated with the means of total counts and total taxa per sample. In the majority of cases, traveling kick samples had the lowest coefficients of variation while Surber samples had the highest coefficients of variation for these parameters. For example, at the upstream control station, PIBS reproducibility was similar to, although slightly lower than, kick samples for total count data (23.9 percent CV vs 20.0 percent CV). Surber samples had the lowest reproducibility for total number of taxa at this station, with PIBS and traveling kick samples, respectively, showing an improvement in reproducibility. At the stations in the vicinity of Piceance Creek, the differences between sampling method reproducibility were much more striking than at the upstream control station.

The significance of differences between sampling methods in the mean total count per sample and the mean number of taxa per sample was tested using analysis of variance (ANOVA) procedures (Sokal and Rohlf 1969). A two-way factorial analysis of variance (ANOVA) with fixed effects was used to test the differences among methods of macroinvertebrate collection upstream and downstream from Piceance Creek. A single classification ANOVA was used to test the differences among these methods at the upstream control station. Bartlett's test for homogeneity of variances was applied to determine if any heteroscedasticity was present in the data (Sokal and Rohlf 1969). No heteroscedasticity was detected in any of the analyses at the 0.05 probability level. Based upon these results, it was accepted that the assumptions of normality and homogeneity of variances underlying ANOVA were not violated and that the tests performed were valid (Sokal and Rohlf 1969).

Significant differences were detected between stations (locations) and methods of collection upstream and downstream from Piceance Creek during fall 1977 for both total count and number of taxa data (Table 2). On the other hand, total count and total number of taxa data were not significantly different (P=0.05) during spring 1978 in terms of the method of sample collection employed (Table 3). There were significant differences (P=0.05) between stations, however, for both total counts and number of taxa during this sampling period.

TABLE 1. MEANS ($\bar{X}$), SAMPLE SIZES (N), AND COEFFICIENTS OF VARIATION (CV) FOR TOTAL COUNTS AND TOTAL NUMBER OF TAXA PER SAMPLE FOR ALL SAMPLES COLLECTED

		Total Counts		Total Number Taxa	
Sampling Method, location	N	$\bar{X}$	CV	$\bar{X}$	CV
10/4/77					
Surber, downstream	5	1,031	42.5	25.6	7.1
STKM, downstream	5	1,371	36.9	28.4	8.4
Surber, upstream	5	336	51.5	17.2	19.8
STKM, upstream	5	777	23.5	23.0	16.6
All Surbers	10	683	48.8	21.4	12.8
All STKM samples	10	1,074	36.1	25.9	12.1
All samples, upstream	10	556	31.9	20.1	18.0
All samples, downstream	10	1,200	40.0	27.2	7.6
4/3/78					
PIBS, downstream	5	1,190	55.6	23.2	12.7
STKM, downstream	5	1,641	43.3	20.8	7.1
PIBS, upstream	5	59	54.2	7.8	21.0
STKM, upstream	5	181	31.4	9.8	16.8
All PIBS samples	10	625	75.1	15.5	15.4
All STKM samples	10	911	55.4	15.3	10.2
All samples, upstream	10	120	51.0	8.8	18.7
All samples, downstream	10	1,416	48.6	22.0	10.6
4/4/78					
Surber, control	5	654	42.3	15.2	23.4
PIBS, control	5	1,002	23.9	22.4	21.8
STKM, control	5	1,661	20.0	23.8	18.6

In contrast to the stations upstream and downstream from Piceance Creek, there were significant differences between methods of macroinvertebrate collection at the upstream control station during spring 1978 for both total counts and total number of taxa collected (Table 4). Patterns of similarity between means of total counts and total taxa at the upstream control station during spring 1978 were tested using Student-Newman-Keuls stepwise multiple range procedure (Sokal and Rohlf 1969).

TABLE 2. TWO-WAY FACTORIAL ANALYSIS OF VARIANCE OF TOTAL COUNTS AND TOTAL NUMBER OF TAXA FOR FALL 1977 SAMPLES (The locations tested were upstream and downstream from Piceance Creek and the methods tested were Surber and traveling kick.)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
TOTAL COUNTS				
Totals	19	4,940,501.20		
Location	1	2,074,968.20	2,074,968.20	15.8969**
Methods	1	764,405.00	764,405.00	5.8563*
Interaction	1	12,700.00	12,700.00	0.0973
Error	16	2,088,427.20	130,526.70	
TOTAL NUMBER OF TAXA				
Totals	19	500.55		
Location	1	252.05	252.02	29.0548***
Methods	1	101.25	101.25	11.6715**
Interaction	1	8.45	8.45	0.9741
Error	16	138.80	8.68	

* = Significant at 0.05 probability
** = Significant at 0.01 probability
*** = Significant at 0.001 probability

Standardized traveling kick samples contained significantly larger numbers of animals per sample than Surber or PIBS samples while the Surber and PIBS samples did not differ significantly (Table 4). High variability of small area samplers has definite disadvantages as exemplified in this case by the fact that there were no statistical differences between Surber and PIBS sample means while there was an actual difference of greater than 300 animals per sample (Table 4). With one exception, however, the STKM provided a higher mean number of animals and taxa per sample than either the Surber sampler or the PIBS (Table 1).

TABLE 3. TWO-WAY FACTORIAL ANALYSIS OF VARIANCE OF TOTAL COUNTS AND TOTAL NUMBER OF TAXA FOR SPRING 1978 SAMPLES (The locations tested were upstream and downstream of Piceance Creek and the methods tested were PIBS and traveling kick.)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F
TOTAL COUNTS				
Totals	19	12,737,841.80		
Location	1	8,392,896.80	8,392,896.80	35.3384***
Methods	1	410,124.80	410,124.80	1.7268
Interaction	1	134,808.20	134,808.20	0.5676
Error	16	38,000,012.00	237,500.75	
TOTAL NUMBER OF TAXA				
Totals	19	960.80		
Location	1	871.20	871.20	213.7914***
Methods	1	0.20	0.20	0.0491
Interaction	1	24.20	24.20	5.9387*
Error	16	65.20	4.08	

* = Significant at 0.05 probability
*** = Significant at 0.001 probability

SELECTIVITY OF SAMPLING METHODS

Species selectivity by the various sampling methods was not striking at the upstream control station, although some evidence for sampler selectivity did exist in the data (Table 5). It appeared that chironomids accounted for a higher mean percentage of the total number of animals per sample collected (percent total) with the Surber sampler than with the PIBS or STKM at the upstream control station. Traveling kick samples had a higher mean percent total for Hydroptila sp. than Surber and PIBS samples (Table 5). Ephemerella inermis also appeared to be collected most effectively by the standardized traveling kick method, and least effectively by the Surber sampler.

TABLE 4. ANALYSIS OF VARIANCE AND STUDENT-NEWMAN-KEULS STEPWISE MULTIPLE RANGE TEST (SNK) OF TOTAL COUNTS AND TOTAL NUMBER OF TAXA AT THE UPSTREAM CONTROL STATION, SPRING 1978 (The methods tested were Surber, PIBS, and standardized traveling kick. Non-significant ($p = 0.05$) subsets of group means are indicated by vertical lines; significant ($p = 0.05$) differences between group means are indicated by horizontal lines.)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Method	Mean	SNK
TOTAL COUNTS							
Total	14	3,592,400.0			Surber	654	
Methods	2	2,613,200.0	1,306,600.0	16.0124**	PIBS	1,001	
Error	12	969,197.2	81,599.8		Traveling kick	1,661	
TOTAL NUMBER OF TAXA							
Total	14	437.7333			Surber	15	
Method	2	212.9333	160.4667	5.6833*	PIBS	22	
Error	12	224.8000	18.7333		Traveling kick	24	

* = Significant at 0.05 probability
** = Significant at 0.01 probability

TABLE 5. MEAN PERCENTAGES OF TOTAL COUNTS PER SAMPLE FOR ALL MAJOR SPECIES COLLECTED IN ALL SAMPLES DURING THE STUDY (A major species is one that represented at least 10% of the total count of any sample set. S = Surber sampler, K = 30-second traveling kick method.)

Taxa	Downstream Piceance Creek 10/4/77		Upstream Piceance Creek 10/5/77		Downstream Piceance Creek 4/3/78		Upstream Piceance Creek 4/3/78		Upstream Control Station 4/4/78		
	S	K	S	K	PIBS	K	PIBS	K	S	K	PIBS
Chironomidae	5.2	4.8	7.0	6.2	18.1	23.2	19.6	11.4	58.8	40.5	41.7
Oligochaeta	0.8	0.5	5.3	1.1	29.3	7.5	18.5	16.0	7.2	5.2	8.9
Ephemerella inermis	0.4	1.3	1.4	3.4	8.1	16.5	6.9	12.2	3.2	16.1	9.0
Tricorythodes sp	48.7	29.3	14.0	43.5	20.4	31.5	1.5	1.3	0.0	0.1	0.1
Baetis sp	0.2	1.3	0.6	0.6	9.0	10.5	36.5	40.7	10.3	20.9	8.9
Pseudocloeon sp	4.8	15.4	4.4	9.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Rithrogena undulata	0.0	0.3	20.8	12.4	0.2	0.4	2.6	3.0	0.0	0.0	0.0
Isoperla sp	0.3	1.3	1.0	1.3	1.3	0.9	9.6	8.2	0.1	0.3	0.2
Cheumatopsyche spp	12.6	12.7	27.1	9.2	3.4	2.3	0.3	0.8	0.1	0.1	0.1
Hydropsyche spp	20.3	22.9	12.6	5.4	6.3	3.0	1.4	0.4	0.0	0.1	0.1
Hydroptila sp	1.3	0.6	0.0	0.5	0.3	0.2	0.0	0.1	12.3	4.3	14.9

At the station upstream from Piceance Creek in spring of 1978, chironomids appeared to have been collected slightly more effectively by the PIBS, while Ephemerella inermis was again favored by the STKM. The STKM and PIBS methods appeared to be quite selective at the station downstream from Piceance Creek during spring 1978, with oligochaetes comprising 22 percent more of the mean percent total in the PIBS than in STKM samples. On closer inspection, one highly aberrant PIBS sample was discovered with 69.4 percent oligochaetes in it. Percentage data based on relatively small total counts ($\simeq$300) is highly sensitive to the widely variable results obtained from sampling patchy benthic communities with small-area samplers, and must be interpreted with care.

Results of sampling during the fall 1977 indicate that the Surber sampler and the STKM were very selective at stations upstream and downstream from Piceance Creek (Table 5). At the station upstream from the creek, STKM samples contained higher percentages of Tricorythodes sp., while Surber samples contained higher percentages of Rithrogena undulata, Hydropsyche spp., and Cheumatopsyche spp. This pattern was almost reversed at the station downstream of the creek where Surber samples contained much higher percentages of Tricorythodes sp. than did STKM samples. Unlike the spring data, no anomalies existed in the raw data to account for this pattern.

It was interesting to note that in most cases there were considerable differences in the species composition of samples collected in the same season upstream and downstream from Piceance Creek. In a majority of cases these differences were evident in both methods of collection used. The percentages of Tricorythodes sp. in samples collected in fall 1977 both upstream and downstream from Piceance Creek were notable exceptions.

TIME REQUIRED FOR SAMPLE PROCESSING

All methods of macroinvertebrate collection compared at the stations upstream and downstream from Piceance Creek required very similar amounts of time to process (sort and count) (Table 6). Surber samples at the upstream control station, however, required the least amount of time to process, with PIBS and STKM samples, respectively, requiring an increasing amount of time for processing.

Differences in the time required for processing macroinvertebrate samples were tested using the same methods outlined previously (Bartlett's ANOVA, and SNK). No significant differences in sample processing time ($p = 0.05$) existed between individual methods of macroinvertebrate collection at stations upstream and downstream from Piceance Creek during fall or spring. Differences did exist among stations (locations) near Piceance Creek during both spring and fall sampling periods (Table 7). Differences in processing time between methods were significant ($p = 0.05$) at the upstream control station in spring 1978. All sampling methods tested at this station required a significantly different amount of time ($p = 0.05$) to process as indicated by SNK result.

TABLE 6. MEANS ($\bar{X}$), SAMPLE SIZES (N), AND COEFFICIENTS OF VARIATION FOR PROCESSING TIME PER SAMPLE IN MINUTES. COST-EFFICIENCY ESTIMATES ARE ALSO PRESENTED (C/T = The number of animals processed per hour, n = the estimated number of samples required for a given level of precision, and CE = $n(\bar{X}/60)$.)

Sampling Methods, locations	N	Processing time in minutes $\bar{X}$	CV	Cost-Efficiency Estimates C/T	n	CE
10/4/77						
Surber, downstream	5	1,125	37.1	54	22	417.6
30-Second Kick, downstream	5	1,071	48.2	78	17	299.7
Surber, upstream	5	594	47.5	36	34	332.5
30-Second Kick, upstream	5	677	33.3	66	7	76.8
All Surbers	10	874	41.0	48	--	--
All 30-Second Kicks	10	870	45.6	72	--	--
All samples, upstream	10	646	39.7	54	--	--
All samples, downstream	10	1,098	48.7	66	--	--
4/3/78						
PIBS, downstream	5	809	25.5	90	38	513.9
30-Second Kick, downstream	5	341	20.5	120	23	324.0
PIBS, upstream	5	82	70.2	42	36	49.5
30-Second Kick, upstream	5	120	31.6	90	12	24.3
All PIBS samples	10	456	34.1	84	--	--
All 30-Second Kicks	10	480	26.0	114	--	--
All samples, upstream	10	101	48.9	72	--	--
All samples, downstream	10	835	23.1	102	--	--
4/4/78						
Surber, control	5	225	41.6	174	22	82.7
PIBS, control	5	420	44.0	144	7	49.3
30-Second Kick, control	5	734	9.8	138	5	60.3

TABLE 7. ANALYSIS OF VARIANCE OF PROCESSING TIME PER SAMPLE IN MINUTES FOR THREE SAMPLING DESIGNS (Two-way ANOVA's were used for the tests bracketing Piceance Creek. Single-classification ANOVA and Student-Newman-Keuls stepwise multiple range test (SNK) were used at the upstream control station. Significant (P = 0.05) differences between group means are indicated by horizontal lines. N/A - not applicable.)

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F	Method	Mean	SNK
Upstream - Downstream Piceance Creek Area, Fall, 1977							
Totals	19	3,330,963.75					
Location	1	1,023,781.25	1,023,781.25	7.1532*			
Methods	1	101.25	101.25	0.0007	N/A	N/A	N/A
Interaction	1	17,111.25	17,111.25	0.1196			
Error	16	2,289,970.00	143,123.13				
Upstream - Downstream Piceance Creek Area, Spring, 1978							
Totals	19	3,019,173.75					
Location	1	2,697,451.25	2,697,451.25	135.7464***			
Methods	1	3,001.25	3,001.25	0.1510	N/A	N/A	N/A
Interaction	1	781.25	781.25	0.0393			
Error	16	317,940.00	19,781.25				
Upstream Control Station, Spring, 1978							
Total	14	849,123.3333			Surber	225	-
Method	2	659,503.3333	329,751.6667	20.8682***	PIBS	420	-
Error	12	189,620.0000	15,801.6667		STKM	734	-

* = Significant at 0.05 probability
*** = Significant at 0.001 probability

COST EFFICIENCY OF SAMPLING METHODS

The cost efficiency of the various sampling methods was estimated in two different ways. The first cost-efficiency estimate was calculated by dividing the mean total counts per sample by the mean processing time in minutes per sample and multiplying by 60, which gives an estimated mean number of animals processed per hour (C/T). The second type of cost-efficiency estimate was derived by first calculating an estimation of the sample size required for a given level of precision by the methods of Steel and Torrie (1960):

$$n = \frac{t^2 \, CV^2}{L^2},$$

where n = estimated number of samples required,
t = Student's t value for a given probability level and degrees of freedom based on the number of replicates (p = 0.05 in the present study),
CV = coefficient of variation and
L = acceptable percent error of the sample mean from the population mean (25 percent in the present study).

The sample-size estimate is then multiplied by the mean number of hours required to process a sample. This cost-efficiency estimate represents the number of hours required to process sufficient samples to provide a total count estimate that would be within 25 percent of the population mean for any sampling method.

Cost-efficiency estimates do not consider the time required for sample collection since the actual sampling time represented only a minor portion of the overall effort in terms of total time expended per sample. However, sampling time is substantially reduced with the STKM since it is possible to collect approximately three STKM samples in the time required to collect a single Surber sample (Kinney, Pollard, and Hornig 1978). In addition, the problems associated with winter sampling are substantially reduced using the STKM.

In the majority of cases, both estimates of cost efficiency indicated that the STKM had the best cost efficiency (Table 6). For example, the STKM required fewer hours to process samples that would be within 25 percent of the population mean as well as producing a higher number of animals per unit processing time than the other two methods (Table 6). In addition, the estimated number of samples required to yield total counts (standing crop) estimates within 25 percent of the population mean was consistently lower for STKM samples than for any other method. In fact, considerably more Surber samples (22) would be required than either PIBS (7) or STKM samples (5) to achieve the same level of precision in the upper White River. The single exception to this pattern was represented at the upstream control station

during spring 1978. In this case, Surber samples contained a higher number of animals per unit processing time than the other two methods tested. The precision of Surber samples, however, was not as good as the other two types of samples as indicated by the higher C.E. index.

DISCUSSION

The present data clearly demonstrated the ineffectiveness of the Surber sampler and the PIBS in riffles with filamentous algal growths (e.g. Cladophora sp.). This is undoubtedly a function of the small area covered for each sample and the inherent patchiness of the stream benthos. On the other hand, Surber samplers and the PIBS performed reasonably well at the upstream control station, indicating that in some riffle habitats a small-area sample would provide a sufficient number of animals and taxa per sample to provide realistic descriptions of macrobenthic community composition. The present study clearly demonstrated, however, that the STKM was superior to or equally effective as the PIBS or Surber sampler for purposes of biological monitoring. Although the PIBS and Surber samplers should have provided very similar estimates of species compositions and density, these data clearly demonstrated that this was not the case. This was particularly interesting since the method of sampler employment was very similar and both samplers collected animals from approximately the same bottom area.

It is obvious from these data that different methods of macroinvertebrate collection yield different estimates of benthic community composition. In addition, the PIBS, when compared to the Surber sampler, collected larger numbers of organisms and taxa per sample although the differences in total counts may have been a function of the high variability of these samplers. Sampler selectivity has been reported by other investigators using other methods of macroinvertebrate collection (Albrecht 1961; Hynes 1961). Precise estimates of benthic standing crop are not obtained using the Surber sampler as has been vividly pointed out by Kroeger (1972). It is evident that none of the sampling methods presently available for macroinvertebrate collection from rocky-bottom stream substrates provide an unbiased estimate of benthic standing crop or community composition.

Choosing a methodology that yields the lowest possible replicate variability and the highest capture efficiency per sampling effort is much more important to sampling program design than the "quantitative" nature of the sampling method since no method presently available is unbiased. Although the STKM would not be considered strictly "quantitative" by most benthic biologists, samples collected with the STKM can provide a reliable index to standing crop because of its low replicate variability. For purposes of determining community changes over time, relatively low variability is of paramount importance. If estimates of standing crop per unit area are necessary, an enclosed-design small-area sampler would, in relatively productive areas, provide adequate data, although a large number of samples

may be required to adequately determine absolute values for standing crop. It is unlikely, however, that a small-area sampler would provide useful data in the patchy, faunal-poor reaches of western streams.

All major taxa collected by comparable PIBS or Surber samplers were also well represented in STKM samples. In most cases the efficiency of the STKM in terms of the number of animals processed per unit time was also higher than comparable Surber or PIBS samples. For these reasons, the STKM is considered the best method for collecting stream macroinvertebrates from rocky bottom substrates (rubble, coarse gravel, etc.), and is specifically recommended for use in the White River in proximity to oil shale development areas.

It should be noted at this time that the data presented in this study represent an ideal data base from which to develop biological monitoring designs for the White River in the vicinity of Piceance Creek and in the upstream reaches of the White River between Buford and Meeker Dome. It is evident from the estimated number of samples required to obtain standing crop values within 25 percent of the population mean (Table 7) that precise estimates of standing crop would require an unrealistic amount of sampling effort. It was possible, however, to detect differences in standing crop per sample and total number of taxa per sample between methods and stations when five replicate samples were collected. In addition, five STKM samples generally collected 1,000 or more animals, allowing reliable species percentage data to be generated. Comparisons of total counts, total number of taxa, and percent species composition of samples collected at stations bracketing the source of potential water pollution from oil shale development should provide the information necessary to detect any associated changes in macrobenthic communities.

Owing to the high natural variability in the macrobenthos of this reach of the White River, adequate baseline data must be compiled to allow separation of man-induced changes and natural variability. Since vast differences in communities were apparent during different seasons, it is evident that single-season monitoring in rivers similar to the White River is not sufficient to provide adequate characterization of benthic communities.

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